**Feasibility Study for**

**Fire History of the North Dakota Badlands**

Final Report to

Theodore Roosevelt Nature and History Association

and

Theodore Roosevelt National Park

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## Introduction

Fire was a keystone ecological process that shaped the composition and structure of many plant communities in western North America prior to widespread settlement by non-Native American people. Since widespread settlement that generally began in the mid- to late-19th century, activities such as livestock grazing and active fire suppression have led to a reduction in or, in most cases, complete exclusion of fire occurrences in most ecosystems (e.g. Savage 1991, Covington and Moore 1994, Touchan et al. 1995, Swetnam and Baisan in press). A historical perspective on pre-settlement fire regimes is therefore needed to understand the role that naturally-occurring fire may have had in influencing plant communities and its relationships with other ecosystem processes.

This report summarizes results from an investigation into the feasibility of reconstruction of pre-settlement fire history (prior to the late 1800s) in the Little Missouri River Badlands of Theodore Roosevelt National Park and surrounding Little Missouri National Grasslands of North Dakota. Plant communities of this region are primarily mixed grass prairies, where direct evidence of past fire frequencies generally cannot be

found. However, there are scattered tree and shrub communities within the grasslands, and we proposed that long-term fire histories could be developed by collection and dendrochronological analysis of fire-scarred trees and examination of tree or shrub stand age structures that may be related to past fire events.

For this study, we surveyed seven sites in woodland communities in the National Park and National Grasslands areas. We collected fire-scarred and other tree-ring samples at six of these sites. These samples were analyzed for crossdating potential and fire history records. Results from these efforts suggest that reconstruction of long-term fire history in the North Dakota Badlands is possible using techniques described in this report, but will need to be interpreted carefully in view of the nature of the record of past fire that is preserved on the landscape today.

**Methods**

We visited seven sites in the Little Missouri River Badlands in August, 1995, to assess their suitability for fire history studies (Figure 1). This survey primarily involved looking for fire-scarred trees, especially those exhibiting multiple fire scars visible in fire-created "cat-faces". At five of the sites, we collected fire-scarred cross sections using a chainsaw. Fire-scarred cross sections were removed from Rocky Mountain juniper (*Juniperus scopulorum*), ponderosa pine (*Pinus ponderosa*), limber pine (*Pinus flexilis*), and green ash (*Fraxinus pennsylvanica* var. *lanceolata*). Full cross sections were generally removed from stumps or downed logs while every effort was made to avoid felling living or standing dead trees by removing only partial cross sections from the fire-scarred area of a tree's stem. We also collected cross sections from selected juniper, pine, and sagebrush (*Artemesia tridentata*) trees and shrubs to assess synchrony of establishment or death dates with dated fire events. Finally, we sampled living trees at some of the sites using increment borers, both to examine age structure and crossdating potential and to provide dating control for remnant (dead) material (e.g. Brown and Swetnam 1994). Table 1 lists material collected at each site.

After return to the Laboratory, cross sections were surfaced using a hand planer and belt sander down to 400 grit sandpaper. Increment cores were surfaced with a belt sander and hand sanding. Fine sanding was necessary to observe cell structure within annual tree rings. All cross sections and cores were dendrochronologically crossdated to provide absolute dates for fire scars or pith or death dates (Stokes and Smiley 1968, Swetnam et al. 1985). Crossdating involved cross-matching climate-affected patterns of tree ring characteristics from tree to tree at a site or between sites to account for ring

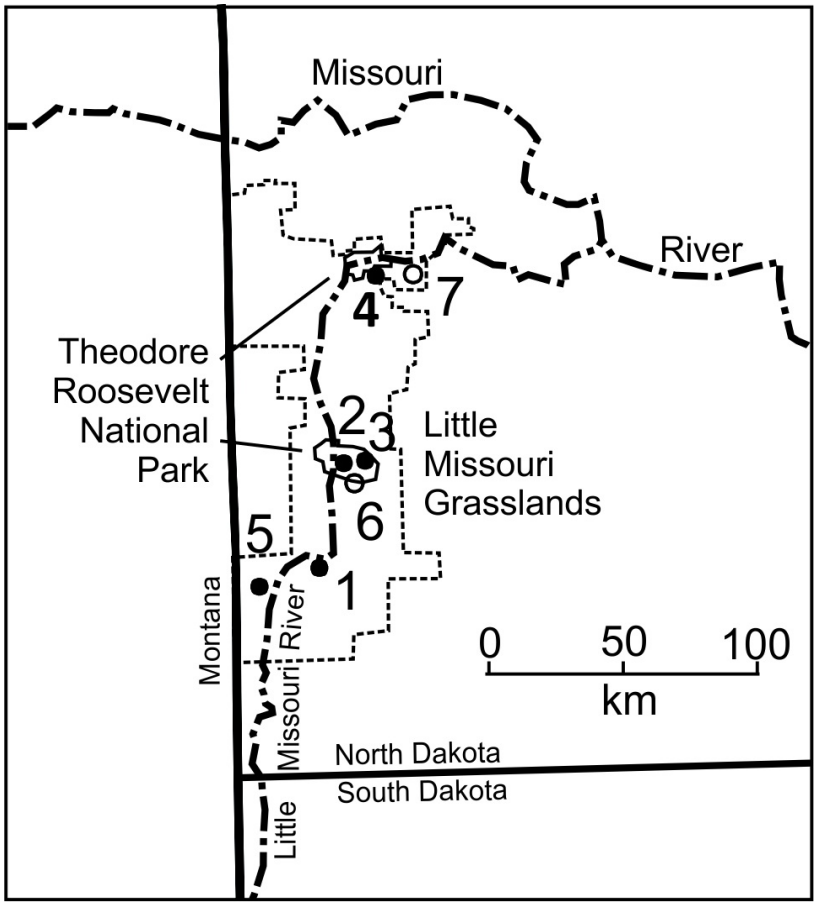


**Figure 1.** Location of fire history sites collected and examined for this study.

**Table 1.** Sites examined, legal locations, and samples collected for this feasibility study. Site numbers correspond to those in Figure 1.

| Site | Location | Samples collected |
|---|---|---|
| 1. Burning Coal Vein Fire (BCF) | T.136N. R.102W. sec 10,15 | 20 cross sections (all ponderosa pine); 2 living trees cored |
| 2. Theodore Roosevelt Recent Fire (TRR) | T.140N. R.101W. sec 21 | 14 cross sections (7 juniper, 7 sagebrush) |
| 3. Theodore Roosevelt East (TRE) | T.140N. R.100W. sec 17,18 | 11 cross sections (all juniper) |
| 4. CCC camp (CCC) | T.147N. R.99W. sec 2,11 | 13 cross sections (6 ash, 7 juniper) |
| 5. Little Missouri Limber Pine (LML & LMF) | T.135N. R.105W. sec 30,31 | LMF: 13 cross sections (2 juniper, 11 limber pine); LML 28 living trees cored |
| 6. Medora Ponderosa Pine | T.140N. R.102W. sec 25 | 3 living trees cored (1 core each) |
| 7. Lone Butte Oil Field | T.147N. R.98W. sec 9,10,11,16,17 | No collection |

anomalies such as locally absent rings or false rings (inter-annual latewood bands) in the assignment of calendrical dates. Master skeleton plot chronologies (Swetnam et al. 1985) were first independently derived for each site and then compared to each other and to two published tree ring chronologies for the Northern Great Plains Region (Burning Coal Vein [ponderosa pine] and Theodore Roosevelt National Park [Rocky Mountain juniper]; Sieg et al. 1995).

After crossdating of all trees at a site was verified, dates were assigned for fire scars and other injuries seen in the tree ring series. Positions of fire scars within annual rings (Dieterich and Swetnam 1984, Baisan and Swetnam 1990) were recorded when possible. Scar positions assigned were: unknown earlywood (E): position within the earlywood cannot be defined more precisely; early-earlywood (EE): within first 1/3 of earlywood band; middle-earlywood (ME): second 1/3 of earlywood; late-earlywood (LE): last 1/3 of earlywood; latewood (L): within the latewood band; dormant (D): between 2 rings; unknown (U): position within the ring not possible to define owing to narrowness of ring or quality of scar. It was also not possible to tell if dormant season scars (formed between two rings) occurred in the earlier or later year (i.e., to have been fall fires occurring after growth had ended or spring fires occurring before the growing season began). Assignment of dormant season scar calendrical dates was based on the presence of either latewood or earlywood scars on other trees. If latewood or late-earlywood scars were present on other trees in the earlier year, dormant season scars were assigned to that year. If only dormant season scars were present, fire dates were arbitrarily assigned to the early year since the majority of other year fire scars occurred later in the growing season. After all fire scars were crossdated and scar positions assigned when possible, dates were complied into a fire chronology (*sensu* Dieterich 1980) for each site using program FHX2 (Grissino-Mayer 1995).

**Results and Discussion**

I was able to crossdate fire events at all sites where we collected fire-scarred trees. First, sites surveyed will be described with reasons for collecting in these areas. Results from each site with interpretations of suitability of these data for fire history reconstruction then will be discussed. Site numbers and names correspond to those on Figure 1 and Table 1.

**1. Burning Coal Vein Fire (samples designated as BCF):** Trees at this site were collected from a series of bluffs overlooking the Little Missouri River approximately 5 km

west of Burning Coal Vein campground on the Little Missouri National Grassland. The area covered by collected trees was approximately 50 ha.Twenty fire-scarred trees were collected at this site, of which 18 were successfully crossdated (Figure 2).

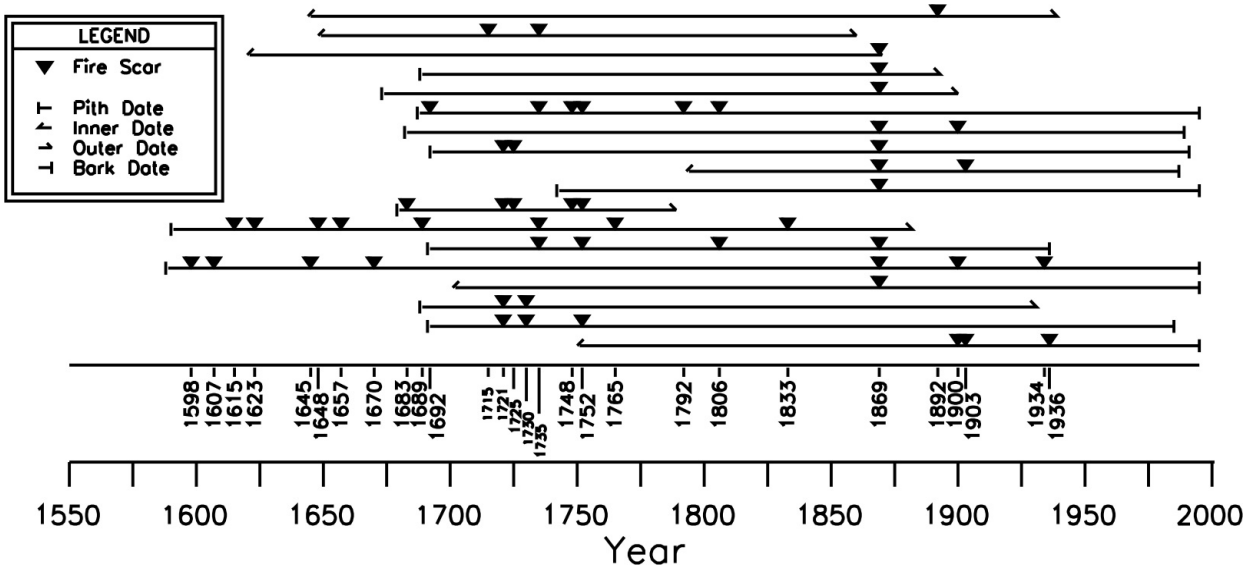


**Figure 2.** Fire chronology for site BCF. Time spans of individual trees are shown by horizonal lines, with fire scars noted by triangles at the dates they were recorded. Dates at the bottom of the graph are fire-scar dates recorded on any tree at the site. All trees are ponderosa pine.

There was widespread scatter of scar dates on different trees as evident in the fire chronology in figure 2. In only a few years were fire scars recorded on two or more trees at the site. The most widespread fire year was 1869, when fire scars were recorded on 10 trees. The 1869 fire year followed a period in the early to mid 1800s when few fire scars were recorded. In addition, few fires were recorded at the site after 1869. Other than 1903, two other trees recorded fires in the twentieth century: BCF 15 in 1934 and BCF 20 in 1936. This general lack of fire dates in the twentieth century follows patterns seen in other ponderosa pine sites throughout the western US (e.g. Savage 1991, Covington and Moore 1994, Touchan et al. 1995, Swetnam and Baisan in press) and in the Northern Great Plains area (Fisher et al. 1987; Brown and C.H. Sieg, unpublished data).

Mean fire-free intervals (MFIs) were calculated for all fire dates recorded and for only those years in which fire scars were recorded on more than one tree. For all fire

scar dates, the MFI was 12 ± 10 years, with a range of 2 to 36 years between recorded fires. Using only those fire dates when fire scars were recorded on more than one tree at the site (N=9), the MFI was 20 ± 24 years, with a range from 3 to 63 years.

Fire scars recorded on only one or a few trees for any fire year as evident from data in Figure 2 suggests at least two possible explanations. First, fires may have been frequent but generally small in size, burning at the base of only one or a few trees. However, trees recording fire scars in different years were often located at opposite sides of the site from each other. For example, trees BCF 7, 12, 14, and 19 recorded fire scars in 1752, but are located at least 250m apart from each other with intervening collected trees between. A second explanation for the scatter in fire scar dates on different trees is that there was discontinuity of surface fuels during most fire years in this dry, open stand of ponderosa pine. In general, woodland communities in prairie ecosystems tend to be located where the effects of episodic fire will not be so great as to completely eliminate the population (e.g. Wells 1965, Steinauer and Bragg 1987, Schuster et al. 1995), although other microclimatic conditions (e.g. higher soil moisture regimes, protection from winds, etc.; Betancourt et al. 1991) must also play a role in woodland location. Discontinuity in surface fuels may have arisen from both scattered grass and herbaceous cover plus extremes in topographic relief in the Badlands breaks at this site. Assuming that there were discontinuous surface fuels underneath the ponderosa pine canopy during most fire years, the fire scar record in Figure 2 may reflect only those areas where fire was hot enough at the base of any individual tree to have created a scar. Similar patchy spatial patterning in fire scar dates has been seen in a ponderosa pine-prairie community at Wind Cave National Park in the southern Black Hills (Brown and Sieg, in preparation). Other support for a discontinuous fuel hypothesis may be present with the 1869 fire date. Fire in 1869 may have been able to scar more trees at the site owing to a possible fuel buildup from needle litter during the relatively fire-free period in the early to mid 1800s (Figure 2).

Most of the fire scars from BCF occurred in the latter part of the growing season or after the growing season ended, although a few fire scars were recorded in the early part of the earlywood. The presence of late season fires fits with recent patterns of fire occurrence in the Northern Great Plains. Higgins (1984) found a majority (73%) of 294 recorded lightning-ignited fires from 1940 to 1981 in the Northern Great Plains grasslands and pine savannas occurred in July and August, with the peak (40%) in August. Although data on radial (ring) growth phenology for ponderosa pine in North Dakota are not available, Fritts (1976) indicates that radial growth in Arizona ponderosa

pine is generally complete by mid-July to mid-August. Assuming a similar or slightly shorter growing season for ponderosa pine in the BCF area, scars recorded as either late-earlywood, latewood, or dormant season would cover the July-August window when the majority of historic fires occurred.

A complicating factor in field examination for fire scars in the Burning Coal Vein area was that a major cause of tree scarring at work in the stand today is from porcupines. Porcupines eat the inner bark (phloem) of pine trees and there was widespread evidence of their recent activity on trees at BCF. Many living trees in the Burning Coal Vein area exhibited scars from porcupine damage. We were careful to collect cross sections for this study from trees that exhibited typical fire-scarred morphologies; i.e. wishbone shaped scars that went all the way to the ground and did not go more than a meter up the tree's bole. Generally, scars formed from porcupine damage did not go to the ground and often went very high up the main stem, often including damage on lateral branches. In addition, there is the possibility that some of the scars recorded in the past were from porcupine damage rather than fire. If there was any question of the origin of a scar when it was crossdated, it was not considered to be a fire scar. These other injuries were not used in calculations of fire frequency.

**2. Theodore Roosevelt Recent Fire (TRR):** This area of scattered juniper woodland and sagebrush was selected since it was on the boundary of a recent fire (1949) recorded on the Park's fire map. We had several goals of collection at this site: 1) to find and date fire scars recorded from the 1949 fire; 2) to assess death dates of remnant juniper trees that may have been killed by the 1949 fire; 3) to look at age structure of sagebrush stands that may have established after the 1949 fire; and 4) to find and date any other fire scars recorded on collected trees.

The fire chronology from TRR is shown in Figure 3 (bottom). I was able to crossdate all of the 14 trees collected, including seven from sagebrush. The sagebrush crossdated well with the junipers, with narrow rings in 1980, 1964, 1961, 1956, and 1936. However, only three of the sagebrush established after 1949 (TRR 9, 11 and 12), while the other four established before that date. All of the sagebrush were collected from a relatively continuous stand inside the 1949 fire boundary drawn on the Park's fire map. It may be that the 1949 fire did not kill all of the sagebrush at the site, or that this area was not burned.

Only one of the junipers recorded the 1949 fire date (TRR 13) while several other scar dates were recorded on other trees (Figure 3, bottom). Three trees recorded fire

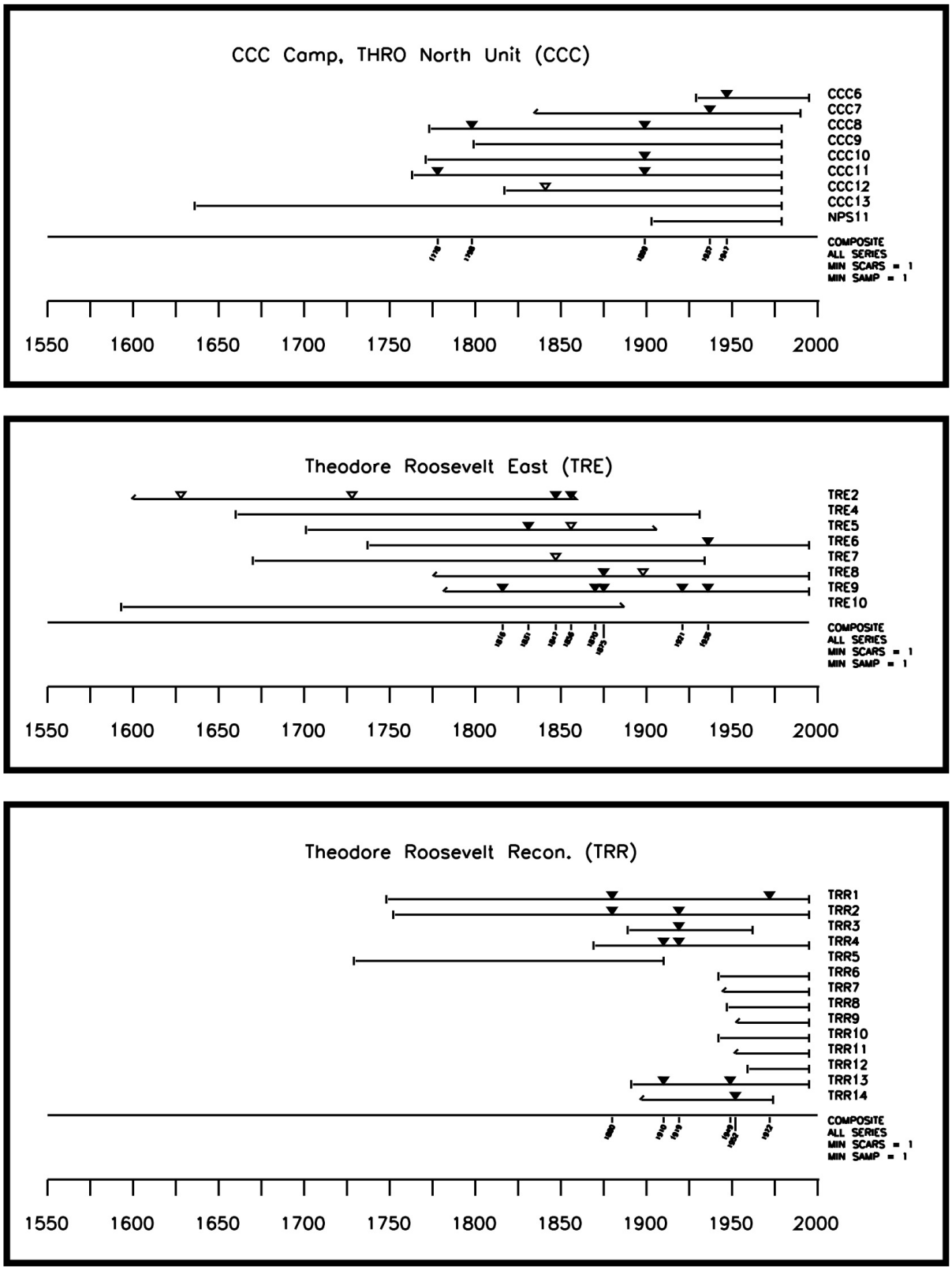


Figure 3. Fire chronology for sites CCC, TRE, and TRR. See caption for figure 2

for explanation. Dates in bottom of graph are for all fire scar dates. In site TRR, trees 6 to 12 are sagebrush, all others are juniper. In site TRE, all trees are Rocky Mountain juniper. In site CCC, tree 6 is green ash, all others are juniper.

scars in 1919, two trees recorded fire scars in 1880, and two others recorded fire scars in 1910. Two other trees recorded injuries in 1952 and 1972. No tree that we sampled died in the 1949 fire but one tree (TRR 5) may have died in the 1910 fire (outside date of 1909).

**3. Theodore Roosevelt East (TRE):** Eleven fire-scarred juniper trees were collected from the badland breaks near the grassland flats above the eastern end of the National Park. We sampled in this area to see if fire frequency may have been higher near the more continuous upland grassland zone.

The fire chronology for this site is shown in the middle panel of Figure 3. Crossdating was more difficult in trees at this site primarily owing to narrow and locally absent rings. Only eight of the eleven collected trees were successfully crossdated. Fire scars were recorded in several years, although again these were not consistently recorded on more than one tree at the site. In only two years, 1875 and 1936, were scars recorded on two trees. We found no record of the 1936 fire on the Park's fire map. Tree TRE 7 may have died in the 1936 fire; the outside rings were very narrow with a death date of 1934 ± 3 years. Sample depth (number of trees per year) is considered to be too low to say anything about increased fire frequency in this area.

An interesting finding at this site was the age of the trees crossdated. TRE 2 had an inside date of 1599 (estimated to be within 20 years of pith) while TRE 10 had a pith date of 1593. The old age of these trees suggests that a longer-term record of fire is possible with more samples from this area.

**4: CCC camp (CCC):** This site was on the edge of a fire that occurred in May, 1980, on the south side of the Little Missouri River across from the North Unit Park Headquarters near the historic CCC camp. We collected 7 junipers killed by the 1980 fire plus 6 ash trees in a stand near the fire boundary. The ash were collected to assess crossdating potential of this species and to see if we could find the 1980 scar on any of these trees. In addition, we were given a cross section from a juniper tree that was collected in this area by NPS personnel (section designated NPS 1).

I was able to crossdate all the junipers from this site (top panel of Figure 3). Most

dated to 1979 as the last complete ring. These trees were killed by the fire before the start of the 1980 growing season. Three trees also recorded dormant season fire scars in either late 1899 or early 1900. This fire has been tentatively assigned to 1900 since an early season fire was recorded in 1900 at BCF (approximately 110 km south). Only one of the ash trees was datable (CCC 6), with the rest having rings to narrow to successfully crossdate. CCC 6 recorded a scar (in 1947), although this was most likely not the result of fire.

**5. Little Missouri Limber Pine (LML and LMF):** Fire-scarred cross sections were collected from eleven limber pine trees and two junipers (samples designated with code LMF) at this site. In addition, increment cores were collected from 28 living limber pine trees to develop into a chronology for climate reconstruction (samples designated LML).

Fire scars were crossdated on most of the cross sections from this site (Figure 4), although, as in all other sites, there was spatial patchiness in scar dates recorded on different trees. Most fire years were recorded by only a single tree, although three trees recorded scars in 1906 and two trees each recorded scars in 1936 and 1951.

The most interesting result from this stand was in terms of ages, both of the limber pine and one of the junipers. Three limber pines (LMF 2, 3, and 7) had pith dates of 1508, 1500, and 1492, respectively. There has been some question as to the origin of this isolated stand of limber pine (Potter and Green 1964, Beckes et al. 1982), specifically that of the possibility of cultural origin. Limber pine has an edible seed and this stand may have been started by intentional human activity. One line of evidence cited for this explanation is that the stand had been considered to be relatively young, with previous estimates of the oldest trees to be at most 281 years old (Beckes et al. 1982). The evidence presented here pushes the age of this stand back to approximately 500 years old. However, this greater age still does not preclude the possibility of human origin of the stand, and the clustering of dates suggests the stand may have originated in a single event.

We also found what may be the oldest known tree in North Dakota at this site. Tree LMF 1, a Rocky Mountain juniper log, had a pith date that has been ring-counted to 1219 and a outside date of 1891, making this tree a minimum of 673 years old. Other ancient juniper remnants were noted near this tree and will be sampled in a future trip.

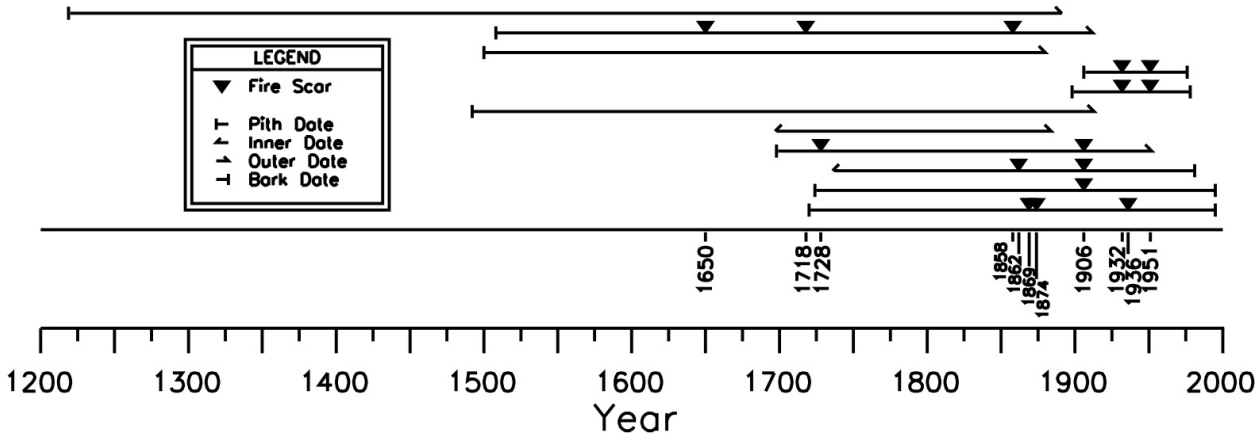


**Figure 4.** Fire chronology for site LMF. Trees 1 and 3 are juniper, all others are limber pine.

**6. Medora Ponderosa Pine:** This stand is on the badlands bluffs just southeast of the eastern on-ramp from Medora to I-90. We examined this stand to see if fire-scarred trees were present. This is likely the northeasternmost stand of ponderosa pine and we were curious as to its potential age structure and fire history possibilities. We found numerous (20+) trees with single fire scars and several (8+) multiple fire-scarred trees (with at least two scars per tree). Several remnant scarred trees were seen, principally logs but at least two stumps (one of which may have had as many as four scars). There was also widespread damage to trees from porcupines, similar to that seen at Burning Coal Vein. Three living trees were cored; these cores crossdated well with other ponderosa pine and juniper samples from the THRO South Unit and Burning Coal Vein area. One of these trees was almost 300 years old. No other samples were taken from this stand, but this area holds promise for future work.

**7. Lone Butte Oil Field:** We examined junipers in this area of bluffs south of the Little Missouri River east of the National Park boundary for potential fire scars. We located at least 20 fire-scarred junipers, some of which (6+) recorded multiple scars. This would also be a potential area to collect in future work.

Other tree-ring material examined included two sections of remnant cottonwood (*Populus deltoides*) and two fire-scarred juniper sections from near Salt Creek in the northern unit of the Park. These sections were collected by NPS personnel. I was not

able to crossdate the cottonwood sections with any of the juniper or pine chronologies from the area. It may be possible to crossdate cottonwood by first developing a chronology from living trees in the area. I was able to crossdate the juniper sections with CCC and other chronologies.

**Summary and Recommendations**

There is good potential for fire history reconstruction based upon data preserved in woodland communities of the North Dakota Badlands. It was possible to crossdate most of the tree-ring material collected for this study with the exception of cottonwood and most of the ash. Fire scars were present on most cross sections collected and were able to be crossdated with confidence.

However, fire history of this area will need to be interpreted carefully in consideration of processes involved in the original recordation of fire occurrences on the landscape. The goal in the development of fire chronologies is to compile comprehensive, long-term inventories of dated fire events for each stand-level site through the use of proxy fire scar records. As suggested by especially the BCF fire chronology, overall fire frequency in any one area of the Badlands may have been high, but, in general, poorly recorded by trees. Fire scars are created when surface fire kills a portion of a tree's growing circumference, forming a characteristic lesion recorded in the tree ring series. Therefore, fire burning at the base of a tree must be hot enough to kill the cambium layer. In fast moving grass fires with short residence times, fire may not be hot enough in all situations to injury cambial tissues, especially on thicker-barked ponderosa pine trees. Furthermore, woodland communities in the Northern Great Plains tend to be located where surface fuels are sparse enough to prevent frequency, widespread fire that would kill trees in the stand. This would also tend to underestimate fires burning up to the edge of a stand but not through it. It is suggested therefore that any estimates of past fire frequency derived for these woodland communities should be considered as minimum frequencies, subject to possible non-recordation of some fire years or smaller scale fires by the proxy record with which we are left.

Especially in the juniper communities, most trees collected for this study contained records of only one or a few fire events. Fire frequency will therefore need to be explicitly stated in terms of spatial area covered by collected trees. For example, at sites TRR or TRE, more fire-scarred trees would need to be selected from a wider area to have confidence that the fire scar record has captured a greater percentage of fires that burned over that area. One may then state what fire frequency was like for that

entire area. Accurate crossdating will be crucial for this endeavor, since the temporal control will be necessary to be sure one has multiple (or the same) fire years recorded on different trees. However, one must also consider that as the size of a collection area increases, mean fire intervals tend to decrease (Brown and Swetnam 1994). Explicit maximum spatial extent of collection units should be defined before sampling begins.

Specific recommendations for future work in order of priority include:

1) A refinement of the ponderosa pine fire chronology from Burning Coal Vein and collection of at least one other ponderosa pine site in this area. Ponderosa pine trees tend to record fire scars without being killed by burning, in contrast to Rocky Mountain juniper. The Burning Coal Vein stand and other associated ponderosa pine stands occur along an extensive stretch of the Little Missouri River. It will be necessary to obtain permission from private landowners to sample in many of the areas of older trees. It should be possible to compare results found at Burning Coal Vein with another similar stand in this area to have some ability to make generalizations about pre-settlement fire regimes. I would also recommend a collection of fire-scarred ponderosa pine trees from the Medora stand, although sample depth in this area may be low.

2) Expansion of the TRR and TRE juniper collections in the South Unit of THRO, and collection of juniper trees in the Lone Butte Oil Field area. These three areas hold promise for development of juniper fire histories, with again the caveat that results will describe a minimum fire frequency for these areas for reasons discussed above.

3) Further attempts at crossdating of cottonwood and other woody species of the area, especially to determine stand age structures that may be related to fire events. This would be needed to be able to say anything about past fire frequency in the riparian and bottomland woodlands. However, crossdating of cottonwood and other hardwoods is often problematic, and these species tend to not be very long-lived which would offer only a limited temporal view of fire history.

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**References**

Baisan, C.H., and T.W. Swetnam. 1990. Fire history on a desert mountain range, Rincon Mountain Wilderness, Arizona, USA. *Canadian Journal of Forest Research* 20:1559-1569.

Beckes, M.R., B.K. Jagler, T.L. Burge, and T.G. Love. 1982. Possible cultural origin of an isolated stand of *Pinus flexilis* in the Little Missouri Badlands. *Journal of the North Dakota Archaeological Association* 1:9-20.

Betancourt, J.L., W.S. Schuster, J.B. Mitton, and R.S. Anderson. 1991. Fossil and genetic history of a pinyon pine (*Pinus edulis*) isolate. *Ecology* 72:1685-1697.

Brown, P.M., and C.H. Sieg. In preparation. Fire and vegetation change at a ponderosa pine-prairie boundary in the southern Black Hills.

Brown, P. M., and T. W. Swetnam. 1994. A cross-dated fire history from a stand of coast redwood near Redwood National Park, California. *Canadian Journal of Forest Research* 24:21-31.

Covington, W.W., and M.M. Moore. 1994. Southwestern ponderosa forest structure: changes since Euro-American settlement. *Journal of Forestry* 92:39-47.

Dieterich, J.H. 1980. The composite fire interval - a tool for more accurate interpretations of fire history. In: M.A. Stokes and J.H. Dieterich (Technical Coordinators), *Proceedings of the fire history workshop, October 20-24, 1980, Tucson, Arizona.* USDA Forest Service, General Technical Report RM-81:8-14.

Dieterich, J.H., and T.W. Swetnam. 1984. Dendrochronology of a fire-scarred ponderosa pine. *Forest Science* 30:238-247.

Fisher, R.F., M.J. Jenkins, and W.F. Fisher. 1987. Fire and the prairie-forest mosaic of Devil's Tower National Monument. *Am. Midland Naturalist* 117:250-257.

Fritts, H.C. 1976. *Tree Rings and Climate*. Academic Press, London. 567 pages.

Grissino-Mayer, H.D. 1995. Tree-ring reconstructions of climate and fire history at El Malpais National Monument, New Mexico. Appendix D: Documentation for the FHX2 software. PhD Dissertation, University of Arizona, Tucson. pp 298-387.

Higgins, K.F. 1984. Lightning fires in North Dakota grasslands and in pine-savanna lands of South Dakota and Montana. *J. of Range Management* 37:100-103.

Potter, L.D., and D.L. Green. 1964b. Ecology of a northeastern outlying stand of *Pinus flexilis*. *Ecol*. 45:866-868.

Savage, M. 1991. Structural dynamics of a southwestern pine forest under chronic human influence. *Annals of the Assoc. of American Geographers* 81:271-289.

Schuster, W.S.F., J.B. Mitton, D.K. Yamaguchi, and C.A. Woodhouse. 1995. A

comparison of limber pine (*Pinus flexilis*) ages at lower and upper treeline sites east of the Continental Divide in Colorado. *Am. Midl. Nat.* 133:101-111.

Sieg, C.H., D.M. Meko, A.T. DeGaetano, and W. Ni. 1995, In press. Dendroclimatic potential in the northern Great Plains. In: J.S. Dean, D.M. Meko, and T.W. Swetnam, eds., *Proceedings of the International Conference on Tree Rings, Environment, and Humanity: Relationships and Processes, 17-21 May, 1994, Tucson, Arizona*. *Radiocarbon* Special Issue.

Steinauer, E.M., and T.B. Bragg. 1987. Ponderosa pine (*Pinus ponderosa*) invasion of Nebraska Sandhills Prairie. *American Midland Naturalist* 118:358-365.

Stokes, M.A., and T.L. Smiley. 1968. *An Introduction to Tree-Ring Dating*. University of Chicago Press. 68 pages.

Swetnam, T.W., and C.H. Baisan. In press. Historical fire regime patterns in the southwestern United States since 1700. In: C.D. Allen (Editor), *Proceedings of the 2nd La Mesa Fire Symposium, March 29-30, 1994, Los Alamos, New Mexico.* National Park Service Publication No.

Swetnam, T.W., M. A. Thompson, and E.K. Sutherland. 1985. Using dendrochronology to measure radial growth of defoliated trees. United States Department of Agriculture Agricultural Handbook No. 639.

Touchan, R., T.W. Swetnam, and H.D. Grissino-Mayer. 1995. Effects of livestock grazing on pre-settlement fire regimes in New Mexico. In: *Proceedings: Symposium on Fire in Wilderness and Park Management; 1993 March 30- April 1, Missoula, Montana*. United States Department of Agriculture Forest Service, General Technical Report INT-GTR-320:268-272.

Wells, P.V. 1965. Scarp woodlands, transported grassland soils and concept of grassland climate in the Great Plains Region. *Science* 143:246-249.